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Authors
Matsumuro, Miki
Kobayashi, Hikari
Shibata, Fumihisa
et al.

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Change of Body Representation in Symmetric Body Parts

Miki Matsumuro (matumuro@rm2c.ise.ritsumei.ac.jp)
Hikari Kobayashi, Fumihisa Shibata, Asako Kimura
College of Information Science and Engineering, Ritsumeikan University, 1-1-1 Noji-higashi
Kusatsu, Shiga 525-8577 JAPAN

Abstract

Many researchers have demonstrated the change of body representation, including the rubber hand illusion and pinocchio illusion. However, they focused on the change of a single body part. The human body has a symmetric structure; therefore, the modification of body representation can be facilitated by the corresponding movement of symmetric parts. In our four experiments, participants moved their hands in different manners with distorted vision and were measured whether their behavior changed throughout the task. The four tasks differed in whether participant's hands were moving simultaneously or separately and whether they moved their hands to the same point or a different point. A behavioral change occurred in all experiments. When the participants moved their hands to the same point simultaneously the greatest behavioral change was facilitated. Neither moving both hands simultaneously or moving to the same position facilitated the change.

Keywords: Body representation; symmetric body parts; proprioceptive recalibration; distorted vision

Introduction

We determine our next actions based on our body representation or a mental model of our bodies (Barsalou, 2008; Warren, 1984). The body representation includes various information about one's body, such as posture, size, bone structure, and material property. The continuous integration of multisensory information keeps updating the body representation, which is sometimes distorted from the actual body. We aim to understand how the body representation is modified or (re)constructed. In this study, we focused on symmetric body parts, upper limb, and conducted various training where the relationship between the left and right-limbs movements was different. Based on the behavioral changes through the training, we argued which independently or dependently controlled the modification of body representation and asked if symmetry plays a role.

Change of Body Representation

Many researchers have demonstrated various body representation changes (Kilteni, Maselli, Kording, & Slater, 2015). Some of them changed the anatomical structure of the body. For example, the length of a nose (i.e., Pinocchio Illusion) or arm in body representation was extended using vibration or sound (Tajadura-Jiménez, Tsakiris, Marquardt, & Bianchi-Berthouze, 2015). Auditory information could also change perceived body size (weight) and a body material (Tajadura-Jiménez, Basia, et al., 2015; Senna, Maravita, Bolognini, & Parise, 2014).

Change in the perceived position of body part(s) was referred to as a proprioceptive drift in studies of body ownership. One of the well-studied phenomena is the rubber hand illusion where, after a synchronized visuotactile stimulation, participants feel the rubber hand as their hand (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). When participants experience this illusion, they perceive that their hand is located nearest to the rubber hand rather than their actual hand position. It was used as an index of the strength of the body ownership. Additionally, some researchers demonstrated the proprioceptive drift of a whole-body with a similar procedure to that of the rubber hand illusion (Ehrsson, 2007). As demonstrated in those studies, we easily modify our body representation through different experiences; especially proprioceptive information that conveys our body parts' position or posture was easily distorted.

Based on cumulative findings, including the above studies, some researchers, such as Longo, Azañón, and Haggard (2010) and Tsakiris (2010), proposed theories about what body representation is and how it is modified or constructed. The proprioceptive distortion in the previous studies was observed in either a single body part or an integrated whole-body. Therefore, a discussion of body part dependency in the modification of body representation is explored in or investigations.

Aim of This Study

We aim to investigate whether the modification of body representation is facilitated by referring to each body part. Body representation of directly connected parts must affect the representation in whole and parts; the question being, how about distant parts? The human body has a symmetric structure; based on this, we focused on how upper limb symmetry and movement affect body representation.

Because of this symmetric structure, when human moves symmetric body parts from symmetric positions for the same duration at the same speed, those parts return to symmetric positions. For example, put your hands on a desk and then bring them up for 3 seconds at the same speed; your hands will locate the same height from the desk. Many researchers have revealed specific characteristics to the symmetric movements of symmetric body parts for a long time, including its neural mechanism (Swinnen, 2002). If the body parts are stable during the modification process, such as in the

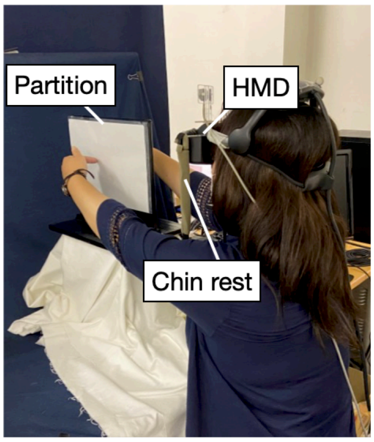
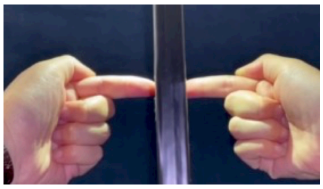


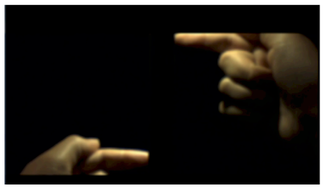
Figure 1: Experimental setting.



(a) Hands without the HMD.

(b) Shift amount 0%.

(c) Shift amount 10%.



(d) Shift amount 20%.

Figure 2: Example visions in each shift amount.

rubber hand illusion, this feature would have little effect; on the other hand, when the participants perform a dynamic task during the modification process, this feature can facilitate the modification of body representation. We decided to employ a task that requires the movement of the hands, through which some researchers demonstrated a proprioceptive drift through the visuomotor synchronized task (Swinnen, 2002; Romano, Caffa, Hernandez-Arieta, Brugger, & Maravita, 2015).

The task that we used to cause body representation modification was simple, the participants moved their limbs as their index fingers touched each other. We added a manipulation to visual information to distort their body representation integration of proprioceptive information during the task, which was not informed to the participants. We evaluated the change in body representation by comparing the action for the same task before and after the above task.

We investigated how two aspects of limb movement affected the body representation changes. The first aspect was whether the participants moved both limbs simultaneously. If the proprioceptive information from both limbs was processed in referring to each other, moving both limbs simultaneously would make the process easy. As a result, it would facilitate the change of body representation. The second was how easily both limbs' movements when their index fingers reached the same point were associated. When the participants observed and experienced such movement simultaneously or successively, they would acquire the baseline position and use it to adjust their body representation.

Experimental Setting

The participants wore a head-mounted display (HMD; MREAL HA-A1, Canon, Tokyo, Japan) with a resolution of 1280×960 pixels; the total field of view was $41^\circ \times 31^\circ$ and displayed at 60 Hz. They sat in front of the partition and set their chin on the chin rest, as shown in Figure 1.

The main task was to move their limbs as their right and left index fingers touched each other. In the experiment, they touched the partition in front of their face to prevent feedback from the distance of two fingers (Figure 1). We asked the participants to lift their arms without bending their elbows until they thought their index fingers were at the same height in front of their face and then to move forward until they touched the partition. We did not allow them to move their hands after touching the partition.

To change the observed position of their hands, we manipulated the scenes displayed on the HMD. Every scene from the participants' perspective was acquired via the camera on the HMD. We divided it vertically into the left and right half and shifted the left half down and the right half up. During the task, the left half included the left hand, and the right half included the right hand.

Owing to this manipulation, the participants observed that their index fingers were at the same height, even though they were at different heights in reality, as shown in Figure 2(a)–2(d). We defined the shift as 0% when we did not manipulate the scenes and 100% when the scenes were shifted by the height of the HMD (i.e., the scenes were perfectly out of the HMD). We selected 0%, 5%, 10%, 15%, and 20% for our experiments (5% and 15% were excluded in Experiment 2 to 4) and did not go over 20% because the participants' fingers were not displayed on the HMD when we shifted more than 20%.

Experiment 1

Experiment 1 was used to confirm that our training task could change participant behavior. The participants moved their hands to the same point simultaneously (i.e., symmetrical movement). We prepared five levels of the shift amount: 0% (control condition), 5%, 10%, 15%, and 20% conditions.

Methods

Participants Twelve undergraduate students participated the experiment (nine females and three males). Their average age was 22.00 years old ($SD = \pm 0.426$).

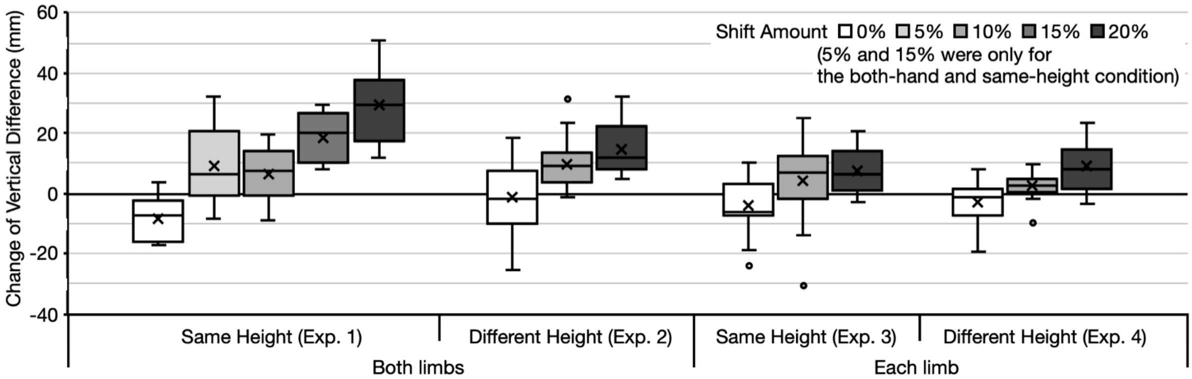


Figure 3: Change in vertical difference for each experiment.

Procedure Each shift condition consisted of three phases: pre- and post-test with training between them. In all phases, we asked the participants to move their limbs as their index fingers were touching each other in front of their face as described in the Experimental Setting section.

Each condition started from the pre-test. The participants sat in front of the partition and laid their arms down on the desk. After a cue from the experimenter, they moved their limbs with the HMD blacked out to touch their index fingers at the same height. We explicitly asked them to rely on the body representation in their mind to accomplish the task. The position of their fingers was recorded; then, the participants laid their arms down on the desk. This was done three times.

The training phase followed the pre-test. The participants moved their limbs according to the same procedure in the pre-test while watching their hands through the HMD. The scene sent to the HMD was manipulated as described in the Experimental Setting section with one of the shift amounts. During the training, we asked them only to move their limbs so that their index fingers reached the same position. We did not instruct them to focus on either visual or proprioceptive information. The training movement was repeated five times.

The participants laid their arms down on the desk for a short time, and we conducted the post-test. The procedure of the post-test was identical to the pre-test. We conducted the procedure above for all shift amounts on each participant. The order of conditions was randomized for each participant.

To cancel the effect of the preceding condition, we gave a five minute rest between conditions. Additionally, before starting the pre-test in each condition, the participants moved their limbs to touch their index fingers without the HMD.

Results

First, we calculated the vertical difference of two index fingers in each trial in the pre- and post-tests by subtracting the left index finger's vertical position from the right index finger. Using the mean of the three trials' vertical differences in each of the pre- and post-tests, we calculated the change of the vertical difference from the pre- to post-test, namely, the length of subtracting the vertical difference in the pre-test from that in the post-test. The manipulation in the training phase aimed to make the participants believe their right hand position was higher than and their left hand position lower than the actual position. When they tried to move their index fingers based on this distorted body representation, compared to the pre-tests, their right index finger would locate at the lower position and the left index finger would locate at the higher position. Therefore, the change of body representation let the change of vertical difference become larger.

The results of all experiments are summarized in Figure 3. In some conditions, the data distribution did not satisfy the normality assumption; Shapiro-Wilk tests showed significance ($p < .05$). We compared the change of the vertical difference among conditions using the Friedman test. There was a significant main effect of the amount of shift ($x2(4) = 34.929$, $p < .001$, $\eta^2 = 0.728$). We performed multiple comparisons using the Wilcoxon signed-rank test with Holm's method to adjust the p-value. The change in the 15% and 20% conditions were significantly larger than in the 0% condition (both $p = .025$, $r > .880$) and the change in the 20% condition was significantly larger than that the 10% condition ($p = .031$, $r = .847$). The differences between the 0% and 5% conditions and between the 0% and 10% conditions were marginally significant (both $p = .065$, $r > .740$). There was a marginally significant difference between the 5% and 20% conditions ($p = .053$, $r = .782$), the 15% and 20% conditions ($p = .076$, $r = .657$), and the 10% and 15% conditions ($p = .067$, $r = .702$). In short, except for the 5% and 10% condition and the 5% and 15% condition (both $p > .200$, $r < .476$), the differences in all pairs were (marginally) significant.

We confirmed the behavioral change through our training. While we found only marginally significant differences in the 5% and 10% conditions that might be because the sample size was not large enough for the statistical significance. In the following experiments, we investigate the effect of the two aspects of limb movement described in the Introduction section: Whether the participants moved their limbs simultaneously or separately and whether they easily compare the movement when their hands reach the same height, Experiment 1 facilitated the representational change the most because it satisfied both simultaneity and observation of the same height.

Experiment 2–4

To test the above points, we conducted three experiments. We used three levels of the shift, 0%, 10%, and 20%, because we had already tested the effect of our training task in Experiment 1. We changed the training phase's task as follows: In Experiment 2, the participants moved their hands simultaneously but touched the different heights. In Experiment 3, they moved their hands separately but touched the same height in two successive trials. In Experiment 4, the participants moved their hands alternatively and never touched the same heights in any successive trials. Additionally, we asked about the ownership feeling to confirm that the participants perceived that they were observing their body parts.

Methods

Participants For all the experiments, there were 20 undergraduate or graduate students (four females in each experiment). Eleven students participated in all experiments, and nine students participated in Experiment 2 and 3. All participants were blind to the study's purpose, and we took more than two days between each experiment. The mean of the participants' age was 21.00 years ($SD = \pm 1.076$) in Experiment 2, 20.95 years ($SD = \pm 1.050$) in Experiment 3, and 21.75 years ($SD = \pm 1.482$) in Experiment 4.

Procedure We gave a different task in the training phase for each experiment. The common procedure for three experiments was that the participants moved their fingers to where a virtual ball(s) was presented until their fingers touched the partition (Figure 4). The number and position of the virtual ball(s) differed according to each experiment's purpose.

Experiment 2: The participants moved both limbs simultaneously and did not observe both hands visually at the same height. In the training phase, two virtual balls were presented at both the left and right side of the partition; the participants were asked to touch them with both hands. We prepared five different vertical positions and selected one of them not to locate the two virtual balls at the same vertical position in the shifted scenes. The participants were able to observe both hands at a time, although they were not visually at the same vertical point. We carefully selected the positions to not bias which hand moved to higher considering the distance of the two balls. The participants experienced five trials.

Experiment 3: The participants moved each limb alternately, and the virtual ball was presented visually at the same height in two successive trials. In each trial, we presented one virtual ball on the left or right side of the partition. The vertical position was identical in each of two successive trials, one for each left- and right-limb movement, in the manipulated display. This selection enabled the participants to associate the

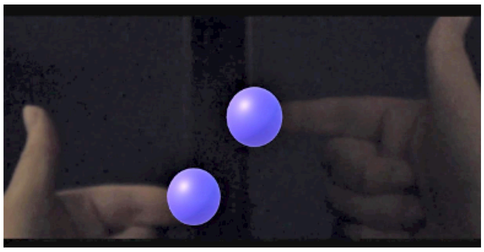


Figure 4: Example vision from Experiment 2.

left- and right-limb movement when they moved it visually to the same vertical position. We counterbalanced which, right or left, ball was first presented. The participants experienced five trials for each of the left and right hand.

Experiment 4: The participants moved each limb alternately, and the vertical position of the virtual ball in any successive trial differed. One ball was presented as done in Experiment 3, whose vertical position was decided by the same rules in Experiment 2. Because of these procedures, the participants could not observe both hands at a time or associate the movements of the left- and right hand when they reached the same vertical position visually. We counterbalanced the initial hand and carefully selected the vertical position in the same manners in Experiments 2 and 3. The participants experienced five trials for each left and right hand.

In all three experiments, after each condition was finished, the participants answered the body ownership questionnaire. We asked one ownership item for each hand: "I felt as if the observed right/left hand was my own arm." This statement was selected from existing questionnaires used in the traditional rubber hand illusion experiments (Botvinick & Cohen, 1998) and modified for our experiment. The participants reported their feeling on a 7-point Likert scale ranging from "-3" (totally disagree) to "$+3$" (totally agree). The other procedures were identical to those in Experiment 1. We repeated the above procedures for three conditions (0%, 10%, and 20%) and randomized the order of three conditions for each participant.

Results

We used the same index and the analysis methods as Experiment 1. The results were summarized in the right three blocks of Figure 3. In all experiments, the main effect of the shift amount reached significance: Experiment 2 $x^2(2) = 16.900$, $p < .001$, $\eta^2 = .423$, Experiment 3 $x^2(2) = 12.700$, $p = .002$, $\eta^2 = .318$, and Experiment 4 $x^2(2) = 19.600$, $p < .001$, $\eta^2 = .498$. In Experiment 2, the change of vertical difference in the 10% and 20% conditions was significantly larger than the 0% condition (0% and 10% $p = .006$, $r = .668$, 0% and 20% $p < .001$, $r = .826$). The difference between the 10% and 20% conditions was marginally significant ($p = .083$, $r = .392$). Similarly, in Experiment 3, the change of the vertical difference in the 10% and 20% conditions was significantly larger than the 0% condition (0% and 10% $p = .032$,

Table 1: Ownership scores.

	Shift Amount	Ownership Score (*SD*)	
		Right Hand	Left Hand
Exp. 2	0%	1.550 (1.276)	1.440 (1.353)
	10%	1.450 (1.468)	1.550 (1.317)
	20%	1.250 (1.446)	1.650 (1.309)
Exp. 3	0%	1.850 (1.226)	2.000 (0.973)
	10%	1.500 (1.504)	1.750 (1.164)
	20%	1.550 (1.276)	1.700 (1.174)
Exp. 4	0%	1.850 (1.348)	2.100 (1.119)
	10%	1.800 (1.399)	1.850 (1.226)
	20%	1.650 (1.089)	1.700 (1.174)

Table 2: Result of regression analysis.

Predictor	Estimate	*SE*	*t*-value	*p*-value
Intercept	12.000	3.064	3.917	$< .001$
Hand	4.345	4.333	1.003	0.319
Position	-0.380	4.333	-0.088	0.930
Hand×Position	21.452	6.618	3.241	0.002

* $F(3,68) = 10.800$, $p < .001$

$r = .543$, 0% and 20% $p = .002$, $r = .760$); although there was no significant difference between the 10% and 20% conditions ($p = .259$, $r = .259$). The change in the vertical distance became larger as the shift amount increased in Experiment 4. The difference between all pairs reached significance (0% and 10% $p = .027$, $r = .543$, 0% and 20% $p < .001$, $r = .868$, 10% and 20% $p = .027$, $r = .555$). There was no main effect of the shift amount in both left- and right hand' ownership score in any experiments (see details in Table 1).

These results show that the vertical difference became larger during the training where the participants observed their hands at the manipulated position.

Combined Analysis

We conducted a regression analysis on the results. Our four experiments had a 2 limb (both vs. each) × 2 position (same vs. different) design; these two factors were used as dummy independent variables. The dependent variable was the value of subtracting the change of the vertical difference in the 0% condition from the 20% condition. The model, including both hand and position factors, fit better than the model including either one (vs. only hand $F(1,69) = 6.365$, $p = .014$, vs. only position $F(1,69) = 15.018$, $p < .001$). Including the interaction between the two factors improved the model (Table 2; $F(1,68) = 11.000$, $p = .002$). From the simple slope analysis (Table 3), when the position was the same, using both hands significantly increased the difference in the change of the vertical difference between the 0% and 20% conditions ($t(68) = 5.200$, $p < .001$); in contrast, it was not significant when the position was different ($t(68) = 0.690$, $p = .490$). The effect of the position factor was significant only when the position was same (same $t(68) = 4.200$, $p < .001$; different $t(68) = -0.340$, $p = .731$).

Table 3: Result of simple slope analysis.

	Simple Slope	*SE*	*t*-value	*p*-value
Simple main effect of position				
Hand				
Both	19.89	4.73	4.20	$< .001$
Each	-1.58	4.58	-0.34	0.731
Simple main effect of hand				
Position				
Same	24.61	4.73	5.20	$< .001$
Different	3.14	4.58	0.69	0.490

The analyses results show the following two things: (1) in all experiments, training with the manipulated hand position changes the participants' body representation, resulting in behavioral change. (2) More modification of the body representation happened when the participants could experience where the same position was vertically with both hands, compared to when just using both hands or observing the vertically same position.

General Discussion

To understand the modification process of body representation, we investigated whether the symmetric relationships between the left- and right-limbs facilitated the behavioral change in the task using body representation. We conducted four different tasks during the modification phase, which differed in the following two aspects: (1) whether the participants move their limbs simultaneously and (2) whether they could easily associate each limb's movements when their hands visually reached the same position. From the results of the experiments, we confirmed that the behavioral change occurred during all four tasks. Additionally, the task where the participants moved their limbs to the same position simultaneously brought the biggest change; and there was no difference in the other three tasks.

It is not surprising that we observed the behavioral change in all experiments. Previous studies showed that the participants perceived their hand or a part of their body drift toward the object by feeling it as a part of their own body (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). In this study, the participants observed their own hands; hence the ownership feeling did not differ according to whether we added manipulation to visual information. In the last three experiments, the averaged ownership score across the left- and right-hands was around 1.5 or higher in all conditions. Additionally, based on their comments after the experiments, we confirmed that the participants did not notice that their observed scene was distorted. Owing to the sufficient ownership feeling, the behavioral change occurred following only five training trials; even though in the previous studies, several minutes was needed to induce the drift.

Experiment 1 showed a significantly larger change than the other three experiments. This means that to facilitate a change in body representation, the participants need to observe and experience both hands' movement reaching the same position visually in one trial. We had predicted that although the effect would be smaller than Experiment 1, either moving both limbs (Experiment 2) or experiencing the same position successively (Experiment 3) could also facilitate the change. Those movements gave the participants a reference position to modify their body representation. However, the amount of change in those two experiments did not differ from the one without the cue, Experiment 4.

That may be because the modification of body representation progressed implicitly. When the participants consciously corrected their erroneous actions, such explicit cues were useful because they show the participants how they had to change their actions. Mazzoni and Krakauer (2006) showed that the explicit strategy using an explicit cue decreased errors in the initial phase; however, as the participants implicitly learned the visuomotor discrepancy, the error gradually increased. In our experiments, the participants did not know the visual information was distorted and did not fail to touch the virtual ball, which meant that they implicitly modified their body representation. Each cue alone (i.e., Experiments 2 and 3) might be useful when the participants use an explicit strategy but not be enough to facilitate the implicit modification.

Studies about motor adaptation (Mazzoni & Krakauer, 2006; Wei & Kording, 2009) and a series of studies about inverted vision from Stratton (1897) have a close relationship to our study. However, those studies mainly focused on the explicit motor error correction process through interactions with the external world. We focused on the implicit process, particularly proprioceptive recalibration, caused by the positional relationship between the body parts and investigated the body parts' dependency in the process. In future work, by instructing the visual distortion, we can make the situation where explicit learning is needed in the same task as this study, which will give us a deep understanding of the modification process of body representation.

One limitation to our experiments is that the task in the pre- and post-tests was almost identical to that in the training phase. Leaving the possibility that the participants in Experiment 1 recalled the training phase's movement and replicated it in the post-test. We can deny the possibility to some extent from the following procedure and data. First, we asked the participants to move the limbs based on their body in their minds. Second, if they replicated the movement, the vertical difference between the left- and right-hands was about 80 mm in the 20% condition, and the change through the training was smaller. Finally, in the comments after the experiments, the participants said that they did not try to replicate the movement in the training phase and had high confidence that they could move their index fingers more accurately in the post-test than in the pre-test. We are planning a new experiment using another task, size discrimination by touch, in pre- and post-tests to confirm this point.

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